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Simulations of low-speed impacts into cohesive aggregates and comparison with experiments on sintered glass bead agglomerates

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Abstract

Small bodies of our Solar System show a great diversity in shapes, sizes and morphologies. However, we do not have direct information on their internal structure. The response of small bodies to various kinds of processes, such as impacts, depends on their internal properties in a way that is not yet well understood. It is therefore important to model the different kinds of structures that can represent a small body and to study their influence on the way a body responds to the different processes undergone during its lifetime. We recently adapted the parallel *N*-body code *pkdgrav* to the modeling of small bodies that are not fully monolithic but that have at least some degree of cohesion. Agglomerates of soft spheres bound together by spring forces that mimic their cohesion are used to represent these bodies. Here, we present a validation test of this adaptation, which consists of comparing low-speed impact experiments on glass bead agglomerates with simulations using the same impact conditions.

1. Introduction

Thanks to the increasing performance of ground-based observations and to the images obtained by space missions, we have an increasing data set regarding the physical properties of the small bodies of our Solar System, showing a great diversity in terms of sizes, shapes and morphologies. Moreover, we also know that these bodies undergo various kinds of processes, such as impacts, shaking and spin ups/downs, during their lifetime. Therefore it is important to understand how the physical properties of small bodies influence their response to those processes, and how in turn those processes may modify their physical properties. We have adapted the *N*-body code *pkdgrav* [3] to model the behavior of cohesive aggregates under various kinds of stresses. As a validation test, we compare impact experiments on sintered glass bead agglomerates to simulations under the same conditions. In general, numerical codes of fragmentation are required to simulate the catastrophic disruption of a small body at high impact speed by computing the crack propagation throughout the body, eventually leading to fragment production (see e.g. [1]). However, in the considered impact experiments, the impact speeds are small enough that the fragmentation is driven by the breakage of bonds between individual beads and not by the fragmentation of individual beads themselves, which makes our adaptation of *pkdgrav* appropriate in principle. The aims of this study are (1) to establish the validity of simulating the salient physics involved in impact experiments adapted to the modeling using our numerical code; (2) to quantify how both laboratory and computational parameters affect outcomes; (3) to justify using this computational method to explore impact outcomes involving gravitational aggregates with weak cohesion, and then to apply it to other processes, such as rotational fragmentation resulting from YORP spin-up.

2. Numerical method

The code *pkdgrav* originally computes the gravitational interaction between up to millions of hard spherical particles and detects their collisions. Collisions are then treated as bounces with dissipation parameterized by normal and tangential coefficients of restitution. In the version adapted to model cohesive aggregates, spring forces between particles, following Hooke's law plus an inelastic damping component, are used to mimic cohesion [4]. The soft sphere discrete element method is also implemented to represent more realistic treatment of contact forces between particles that takes friction into account [5].

3. Impact experiments and simulations

Impact experiments on sintered glass agglomerates consisting of 90 5 mm-diameter beads have been performed [2]. Our numerical model is in principle perfectly adapted to simulate these experiments, as the targets can be modeled using spheres connected by springs whose forces mimic the measured strength between glass beads. Note that the neck between beads developed by the sintering process is solid and different from the neck due to van der Waals force expected for fine particles. We started performing numerical simulations aimed at reproducing the impact experiments with speeds from 40 to 280 m/s that were performed on agglomerates with 40% porosity and two different bulk tensile strengths [2]. Figure 1 shows pictures of a real target and images of a modeled one. For the modeled one, the parameters of the spring forces bonding particles (Young modulus, damping) were adjusted to be consistent with measured strengths between the real beads.

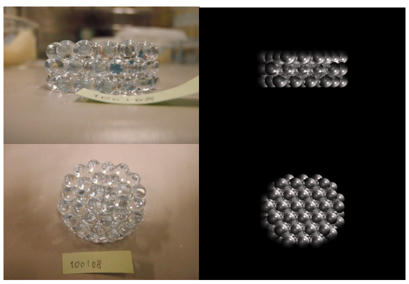

Figure 1: left: experimental target consisting of a sintered glass bead agglomerate; right: modeled target consisting of soft spheres bound together by spring forces. Side and top views are shown.

We first simulated an impact of a small projectile with a speed of 78 m/s. Preliminary analysis shows that simulations reproduce at least qualitatively this experiment. Fragments consist either of individual beads whose links with other beads were fully broken, or of cohesive agglomerates of different sizes depending on the number of particles composing them. Quantitative comparison will be presented concerning the fragment size and ejection velocity distribution for several impact conditions used in the experiments. Results will also be presented covering the parameter space and showing the sensitivity of the outcome to various kinds of parameters that represent different physical properties.

4. Summary and Conclusions

We adapted the *N*-body code *pkdgrav* to the modeling of cohesive aggregates that can be used to represent Solar System small bodies containing some degree of cohesion. We started performing a validation test consisting of a comparison with low-speed impact experiments on sintered glass bead agglomerates. Following this validation, we will be able to cover a wide parameter space and determine the sensitivity of each parameter. We will also explore the behavior of such cohesive aggregates under other conditions, e.g. the rotational excess due to YORP spin-up that can lead to their disruption and that was found to explain the formation of binaries starting from purely gravitational aggregates [6].

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